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Indian Standard

GUIDANCE FOR PULSE TESTING OF RESISTORS

UDC 621·316·8 : 620·1 : 621·374

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Indian Standard
GUIDANCE FOR PULSE TESTING OF RESISTORS

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GUIDANCE FOR PULSE TESTING OF RESISTORS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 21 May 1980, after the draft finalized by the Resistors Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 In electrical and electronic equipment, there is a growing need for resistors which can continuously be loaded with pulsed power resulting in high stresses by voltage, current, and inhomogeneous heating.

0.2.1 The applied pulses cover a large range of shapes, repetition frequencies, and duty cycles as may occur in:

a) control circuits on line frequency (50 Hz),
b) light machinery controls (400 Hz),
c) radio interference suppression on motors of any kind ($<$120 Hz),
d) television fly-back circuits and similar equipment (10 to 20 KHz),
e) data processing ($>$1 MHz), and
f) others.

0.2.2 The peak values of power, voltage, and current occurring in some of such applications will often exceed the usual continuous ratings appreciably. To rate the resistors for continuous loading with the peak values is impossible because of dimensional and economical reasons. On the other hand, high overloads are normally permissible for very short times. The failure mechanisms under pulse load may, however, differ widely from those under steady load even if a steady state is reached, so true pulse ratings can normally not be derived from the usual tests for endurance and overload.

0.3 This standard is largely based on IEC document, 40 (Sectt) 361 'Guidance for pulse testing of resistors', issued by International Electrotechnical Commission (IEC).

1. SCOPE

1.1 This standard provides guidance for testing of resistors, under pulse conditions.

2. TERMINOLOGY

2.1 For the purpose of this standard terms and definitions given in IS: 9470-1980* shall apply.

3. FAILURE MECHANISM TO BE EXPECTED

3.1 Depending on design and size of a resistor, one or several of the following mechanisms may lead to more or less pronounced changes in resistance or to mechanical or electrical breakdown:

a) Temperature gradients between parts of the body and element,
b) Overheating in narrow current paths,
c) Sparking across grooves or from edges in spiralled film resistors,
d) Microwelding of particles in resistor compositions and glazes,
e) Burning out or reopening of conducting paths in composition resistors,
f) Changing of film properties by edge effects,
g) Change in contact resistance between element and terminals, and
h) Puncturing of the insulating cover or the body.

Other failure modes may prevail with specific designs, for example, extremely long or flat ones, or with specific kinds of winding, or surface finish.

4. DESIGN PARAMETERS HAVING A BEARING ON PULSE LOAD CAPABILITY

4.1 The basic construction of the resistor (for example, film, composition, slug, wirewound) and the homogeneity of the resistive element determine to a large extent how the resistor will behave under pulse load.

4.1.1 *Current Effects* will be the more pronounced if the conducting paths are not homogeneous.

4.1.2 *Voltage Effects* rise with the resistivity of element, body, and coating, and with the sharpness of edges.

4.1.3 *Thermal Effects* depend to a large extent on the differences in temperature transient behaviour of the resistive element, of the body, and of the coating. Also the terminations have sometimes to be taken into consideration. The thermal transient behaviour can often be described by a set of temperature time constants and thermal conductivities for different parts of the resistor. Thus the peak element temperature may be considerably higher than the surface hot spot temperature.

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*Method of test for the usability of resistors under pulse conditions.

4.2 The mounting of the resistor may also influence the permissible loads and the thermal time constants involved. It may be necessary to advice a standard mounting device. For an example *see* Appendix A.

5. EFFECTS TO BE MEASURED

5.1 Normally, all failure mechanisms result in a more or less pronounced change in resistance, the direction of which may be meaningful. In extreme cases the change may include shorting or interrupting the resistor.

5.2 Other easily discernible damages are breakdown of the outer insulation or mechanical rupture of the body.

5.3 In more delicate cases and depending on the intending application, beginning of damage may be judged from changes in:

a) noise behaviour,
b) linearity, and
c) temperature coefficient.

6. INFLUENCE OF PULSE SHAPE

6.1 Thermal effects are predominantly covered by the average power in the pulse train and by the energy content in the single pulses of this train. The specific shape of the pulse is, in this respect, of little importance, provided the duration of the pulse permits a reasonable duty cycle and is short as compared to the shortest temperature time constant involved.

In film and wirewound resistors this time constant is normally that of the resistive element including only the nearest parts of body and coating, dependent on their thermal conductivity and heat capacity.

In inhomogeneous films and in compositions, smaller areas may be responsible for the critical time constant. It may be represented by a 'calculatory value' which is derived from the thermal characteristics of the resistor as a whole.

The total temperature time constant controls only the cooling of the resistor to the environment through the relevant thermal resistances and hence has a bearing on the minimum reasonable pulse spacing.

6.2 Voltage effects depend mainly on the peak value and on the steepness of the first and last transitions (rise time and fall time) of the single pulse. The steeper the transition is, the more the transition current tends to leave the resistive paths and to flow through the dielectric materials of body, coating or composition. Very high voltage gradients may result in lowering the conductivity of the dielectrics and more inhomogeneous they are more pronounced are the voltage effects. On very good insulating surfaces, long gliding sparks may develop.

6.3 Current effects are proportional to the voltage effects as long as a resistor can be considered to be really ohmic. This is true as long as the duration of the first (and last) transient is long as compared to the reciprocal of the lowest self-resonant frequency of the resistor. This need not be measurable directly with any impedance measuring device because of high damping, but it may be estimated from dimensions and measurement of very high frequency impedance. When this condition is not fulfilled, a detailed analysis is necessary. Hot spots need special consideration.

7. BASIC CONSIDERATIONS FOR DESIGNING A PULSE TEST

7.1 A pulse test may be designed as an endurance test or as an accelerated test. An accelerated test is only possible if the additional pulse failure mechanisms undergo no further change in the intended range of overstressing. This may vary not only with design but also with resistance value.

7.1.1 *Warm Up Behaviour of a Resistor Under Pulse Load* — In a pulse test which is intended to supplement the usual endurance test, the following should apply:

a) The average power during the test should not exceed maximum dc ratings, and

b) The peak temperature during the test should not exceed the maximum specified temperature at dc ratings by more than a specified value.

Figure 1 shows the power pulses and the corresponding temperature at the surface of the resistor.

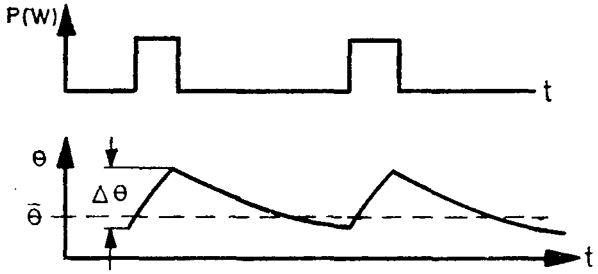

FIG. 1 POWER AND TEMPERATURE AS A FUNCTION OF TIME

The differential temperature in resistors having a two-dimensional element is approximately expressed by equation (1)

$$\Delta\theta = \frac{\hat{P}\,.\,2}{F\,.\,\lambda}\sqrt{\frac{a\,.\,t_1}{\pi}} \qquad .. \quad (1)$$

where

$\hat{P}$ = Pulse power,
a = $\lambda/C\rho$,
c = Specific heat, ⎫
ρ = Density, ⎬ of substrate
λ = Thermal conductivity, ⎭
t_p = Pulse period,
t_1 = Pulse duration, and
F = Element active area.

Approximately the temperature θ then can be expressed by equation (2).

$$\hat{\theta} = \frac{\hat{P} \,.\, R_{th} \,.\, t_1}{t_p} + \triangle\,\theta = \bar{\theta} + \triangle\,\theta \qquad .. \quad (2)$$

Figure 2 shows the normalized pulse power ($\hat{P}/P_r$) as a function of t_1/t_p and t_1. The thermal resistance R_{th} is expressed by equation (3).

$$R_{th} = \frac{\theta_{max} - 70}{P_r} \qquad .. \quad (3)$$

Eqn (2) becomes; $\hat{\theta} = \frac{\hat{P}}{P_r} \cdot \frac{t_1}{t_p}\left(\theta_{max} - 70\right) + \frac{2\hat{P}}{\lambda.F}\sqrt{\frac{a\,.\,t_1}{\pi}}$

or

$$\hat{\theta} = \frac{\hat{P}}{P_r}\left\{\frac{t_1}{t_p}\left(\theta_{max} - 70\right) + \frac{2P_r}{\lambda F}\sqrt{\frac{a.\,t}{\pi}}\right\} \qquad .. \quad (4)$$

For $\theta = \theta_{max}$, the ratio $\hat{P}/P_r$ can be solved

$$\frac{\hat{P}}{P_r} = \frac{\theta_{max}}{\frac{t_1}{t_p}\left(\theta_{max} - 70\right) + \frac{2\,P_r}{\lambda.F}\sqrt{\frac{a\,.\,t_1}{\pi}}} \qquad .. \quad (5)$$

Equation 5 is shown in Fig. 2 for film resistors and in Fig. 3 for wire-wound resistors. The radio P_r/F is essentially constant for different types of resistors within the same technique.

In the upper part of these diagrams destructive tests are plotted for information.

The asymptotic straight part of the curves corresponds to the equation $\hat{P}/P_r = 10/\sqrt{t_1}$, approximately.

Recent measurements have shown that the warming up of film resistors does not follow an exponential law as is assumed in stating a temperature time constant. Instead, an error function has to be considered which comprises the exponential as a limiting case. The deviations are most marked in the very beginning of the warm up (care should be taken with very short or high pulses) and near thermal equilibrium. The latter range

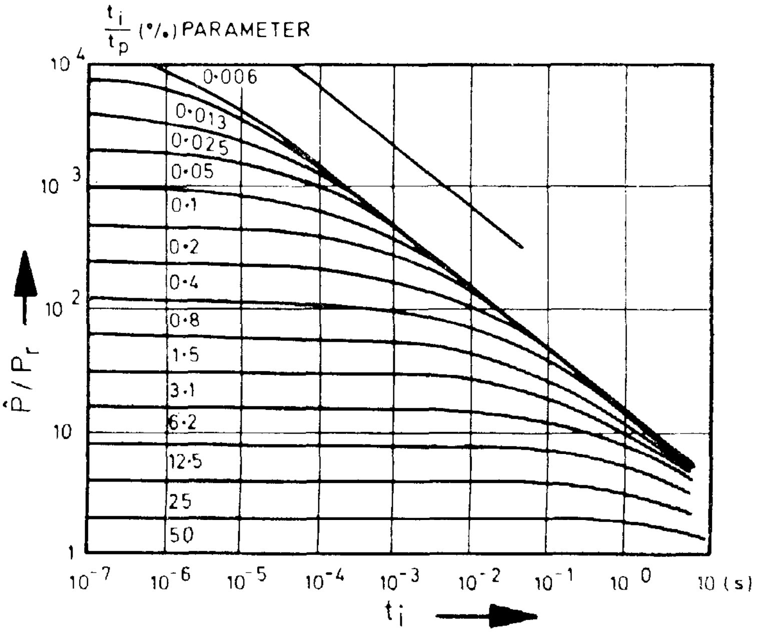

Fig. 2 Normalized Pulse Power Tests as a Function of Pulse Time (t_i) and Duty Cycle (%) for Film Resistors. Limiting Temperature is 150°C (θ_{amb} – 70°C)

is rather unimportant for pulse testing. Both limits can safely be treated by correct calculatory values derived from experimentation.

All these calculations only hold true for a heated cylindrical face in a heat conducting environment. This means that slug type resistors (composition types) should be treated separately.

7.1.2 *Choice of the Repetition Period and Pulse Duration* — A pluse test will normally be conducted for a time long enough to reach a thermal steady state. If the pulse shape has been chosen to deliver the intended peak stresses (*see* **3** and **6**) the average power (or rms voltage) in the pulse train need be adjusted to a value corresponding to the permissible dissipation of the resistor under the existing environmental conditions.

This means:

$$P_0 \geqslant \bar{P} = \frac{1}{t_p \cdot R}\int_{t_1}^{t_2} U^2 dt \qquad \ldots (6)$$

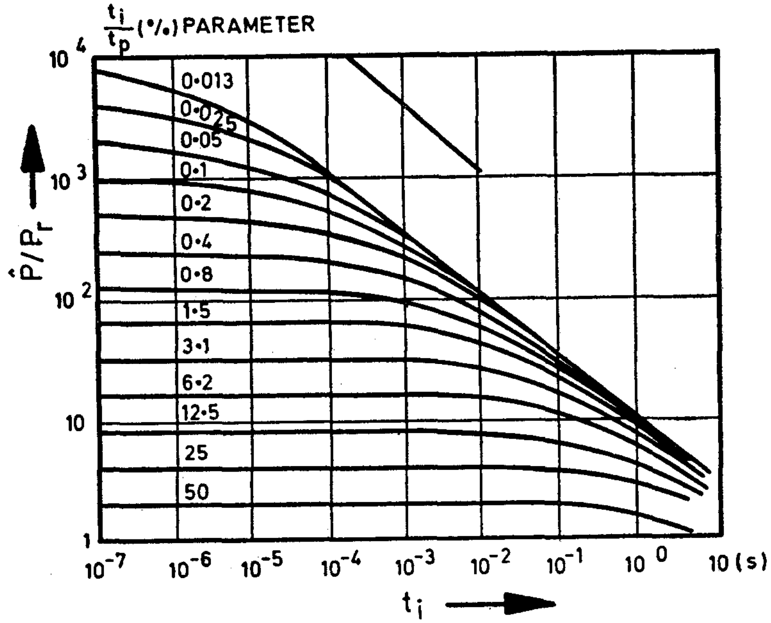

FIG. 3 NORMALIZED PULSE POWER TESTS AS A FUNCTION OF PULSE TIME (t_i) AND DUTY CYCLE (%) FOR WIRE WOUND RESISTORS. LIMITING TEMPERATURE IS 275°C (θ_{amb}=70°C)

where

P_θ = Permissible dissipation at ambient temperature θ,
$\bar{P}$ = Average power in the pulse train,
t_p = Pulse repetition period,
R = Rated resistance,
t_1 = Pulse start time,
t_2 = Pulse stop time, and
U = Momentaneous voltage.

The two important special cases are:

Rectangular pulse:

$$\bar{P} = \frac{t_i}{t_p} \cdot \frac{\hat{U}^2}{R} \text{ with } t_i = t_2 - t_1 \qquad .. \quad (7)$$

and

Exponential pulse:

$$\bar{P} = \frac{\tau_e}{2t_p} \cdot \frac{U^2}{R} \qquad \cdots \quad (8)$$

where

$\tau_e =$ Time constant of decrease of U in the pulse (trailing edge, $R \cdot C$ or $\frac{L}{R}$ depending on the circuit used).

To avoid excessive pulse overlap, t_p shall not be less than 3 τ_e.

7.1.3 *Choice of the Pulse Shape* — Practically occurring pulses may vary very widely in shape. To arrive at a reproducible test, the pulse shape need be standardized. As can be seen from **6**, the most important parameters of the single pulse are:

a) steepness of the first and last transitions,
b) energy content,
c) peak pulse voltage, and
d) pulse duration.

Extremes of all these can only be combined into a rectangular (trapezoidal) pulse. This means that rectangular pulses yield the highest severity, limited of course by the distortions caused in the test set up. Such pulse shape has been specified in the standard pulse test (*see* IS : 9470-1980*) though it may not be the most economic shape to achieve.

If, for a specific case, it is known that the voltage transitions are of minor importance as compared to the peak values of voltage and power, exponential pulses may be used very economically. To keep tests with exponential pulses comparable, the time constants of both the leading and the trailing edge need be specified together with the permitted overshoot.

All other pulse shapes are less desirable because of lesser definition. One possible exemption is defined cut-outs of sine waves of line frequency as may occur in thyristor control circuits.

The pulse peak overload factors against dc or ac use expressed by voltage proportions are:

Power overload factor $c_p = \dfrac{\hat{U}}{\sqrt{\bar{P} \cdot R}} = \dfrac{\hat{U}}{U_R}$

Voltage overload factor $c_u = \dfrac{\hat{U}}{U_{max}}$

Current overload factor $c_1 = \dfrac{\hat{I}}{I_{max}}$ (c_p in the ohmic range)

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*Method of test for the usability of resistors under pulse conditions.

In these equations

$\hat{U}$ = the pulse peak voltage;
$\hat{I}$ = the pulse peak current;
U_r = the rated voltage;
U_{max} = the maximum permissible voltage (for example, limiting element voltage);
I_{max} = the maximum permissible current;
P = the permissible dissipation in the existing environment; and
R = the rated resistance.

The limiting values depend on the relation of the pulse duration to the temperature time constant of the resistor. Calculatory values shall be given in the relevant detail specification because they depend strongly on size and construction of the resistor.

The practical duration of any pulse may, for the purposes of this test, be defined as the time during which the momentaneous voltage is higher than the rated voltage of the resistor.

To adjust for standard testing of the average power in the pulse train, either the pulse repetition period or the pulse duration or both shall be chosen to make $P_0 = p$. The pulse duration should, however, not be longer than is permitted by the temperature time constant of the critical part of the resistor.

If the calculatory basis is taken to be the time constant to warm up the surface of a resistor by electrical load, the pulse duration shall not be longer than $2 \cdot 10^{-5}\, \tau_e$.

NOTE — The temperature time constant of the resistive element may be shorter especially with film resistors.

For longer pulse durations the c_p and c_u values shall be reduced according to a curve pertinent to the resistor typical construction (film, slug, etc). An example for carbon film resistors is shown in Appendix A.

7.1.4 *Dependence of Stress on the Resistance Value Within a Style* — All resistors of a specific style manufactured according to the same technique and with the same size are normally identical in thermal behaviour. They may however differ in their mode of failure according to the resistance value tested. With the lowest resistance values, current effects may be most pronounced. In the medium resistance value, range power effects will prevail. With high resistance values, voltage effects become predominant and may be the primary reason for conducting a pulse test.

In these three resistance value ranges per size, the respective pulse overload factor c_I, c_p and c_u apply (*see* **7.1.3**). Often c_p is considered to be identified with c_I. The power load limitations are dealt with **7.1.2**. Depending on the design of the resistor the permissible peak pulse power is a function of the pulse duration. The peak voltage load capabilities are connected with the limiting element voltage.

The resistance value at which the pulsed power limitation and the pulsed voltage limitation are reached with the same voltage value is different from the critical resistance for steady load (R_{crit}) and is connected to this by the factor $(c_u/c_p)^2$. The (low) resistance value at which the pulse load is limited by a peak current lower than associated with the peak power [that means $(c_p/c_i)^2 < 1$] seems to have no practical importance except with steep last transients of pulses in an inductive load. The respective limiting values are compiled in the following table:

Range	*Current Limited*	*Power Limited*	*Voltage Limited*
R/R_{crit}	$\leqslant (c_p/c_i)^2$	$< (c_u/c_p)^2$ and $> (c_p/c_i)^2$	$\geqslant (c_u/c_p)^2$
Permitted peak voltage $\hat{U}$	$c_i\, I_{max}\, R_r$	$c_p \,.\, U_r$	$c_u \,.\, U_{max}$
Permitted peak current $\hat{I}$	$c_i \,.\, I_{max}$	U/R_r	$c_u \,.\, U_{max}/R_r$
Permitted peak power $\hat{P}$	$\hat{I}^2 \,.\, R_r$	$c^2_p \,.\, P_r$	$\hat{U}^2/R_r$
Average power $\bar{P}$	P_r	P_r	P_r
Duty cycle t_i/t_p (For rectangular pulses)	$1/c^2_i$	$1/c_p^2$	$1/c_u^2$

For definitions of c_p, c_i and c_u *see* **7.1.3**. Values shall be given in the detail specification.

7.1.5 *Choice of the Test Duration* — Most failures caused by pulse load will occur during the first few pulses if the sample is not pulse resistant. So it may be sufficient to continue a pulse test until a thermal steady state is reached provided that the behaviour of the component in standard endurance tests is known, as will normally be the case.

To reach a reasonable safe margin of assessment for pulse ratings, the 100 hours duration preferred in IS: 9470-1980* should be sufficient. In this duration is comprised a warm up from the element temperature at the start of the loading to the limiting element temperature under persistent pulsed stress. The total number of pulses applied is at least several millions.

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*Methods of tests for the usability of resistors under pulse conditions.

If a marked temperature dependence of pulse load capability is supposed it should be preferred to conduct the test at a specified temperature but not to prolong it.

Minimum test durations may be considered on the following basis:

Thermal effects will be covered by rapid heating through the permitted temperature rise and holding for about 10 times the temperature time constant of cooling the surface.

Voltage effects shall be discovered within a few minutes at reasonable voltage overload.

Current effects would normally take a few minutes to develop, in certain cases a few hours.

8. ECONOMICS OF PULSE TESTING

8.1 A pulse test shall not be conducted as a long term high temperature test. This is more economically tested by the various endurance tests at upper category temperature, at 70°C and at other temperatures.

A resistor shall however be pulse tested if it is necessary to assess that the high overloads of short duration occurring in the peak of the pulse and the fast transients in the pulse do not damage the element or the coating. This is only necessary for resistors loaded with pulses regularly and during prolonged times. A pulse test is not necessary for components which are loaded by pulses only occasionally. In such cases the tests given in 'Safety requirements for mains operated electronic and related apparatus for household and similar general use' (*under preparation*) are sufficient.

The evaluation of the test shall mainly consider the deviations from normal endurance.

Another reason for limiting the extent of pulse testing is cost of equipment. Normally every component tested needs its own pulse power stage as is given in IS : 9470-1980*. This is also true for testing with exponential pulses, though the 'power stage' may be much simpler in that case.

Care should be exercised to restrict periodic or lot by lot pulse testing to those components where it is really needed. With type testing a larger amount of pulse testing may be justified, especially where the typical behaviour for a whole family of components can be assessed.

---

*Method of test for the usability of resistors under pulse conditions.

APPENDIX A

(*Clauses* 4.2, *and* 7.1.3)

PULSE LOAD CAPABILITY OF CARBON FILM RESISTORS

For continuous pulse loading the following conditions apply:

a) The pulse peak voltage shall not be higher than

1) $| \hat{U}_2 | \leqslant c_p . \sqrt{P_\theta . R}$ (P_θ = permissible dissipation at relevant ambient temperature)

2) $| \hat{U}_i | = c_u . U_{max}$ (U_{max}=limiting element voltage)

whichever is the lower.

The overload factors c_p and c_u shall be taken from Fig. 4.

b) The average power in the pulse train shall not be higher than the permissible dissipation P_θ at the relevant ambient temperature (*see* **7.1.2**).

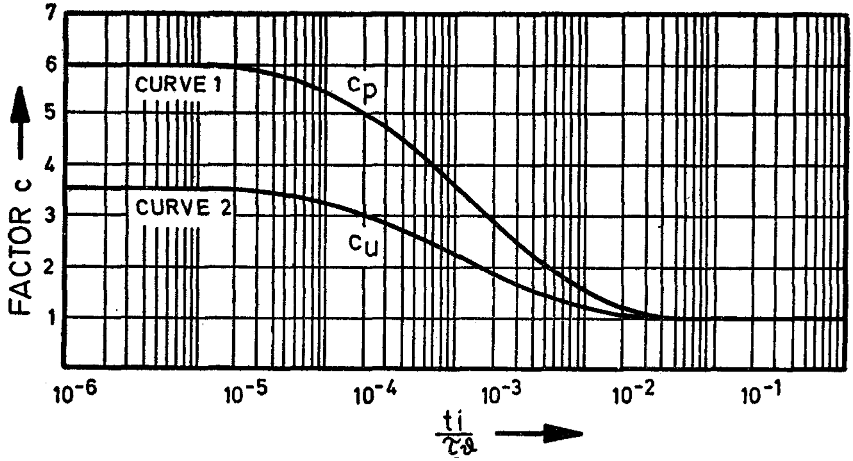


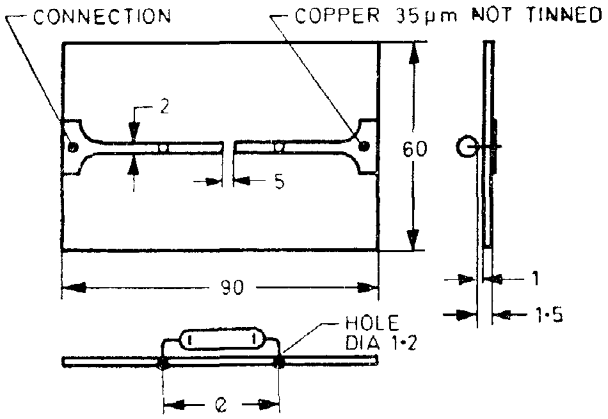
FIG. 4 OVERLOAD FACTORS c_p AND c_u AS FUNCTIONS OF t_i/τ_θ (FOR τ_θ *see* TABLE 1)

The size code refers to nominal length and diameter in mm given by two digits (for example 0933=9 mm diameter, 33 mm long).

If lot by lot or periodic pulse tests are conducted, they shall apply no further overload. To take care of that part of thermal time constant and dissipation which is influenced by mounting, the resistors shall be mounted on the standard mounting plate according to Fig. 5 with the face of the plate vertical and the resistor main axis horizontal.

TABLE 1 TEMPERATURE TIME CONSTANT AND SIZE CODES

Sl No. (1)	Size Code (2)	Temperature Time Constant τ_θ (Calculatory Value) (3)	Limiting Element Voltage (4)
		s	V
1.	0204	2	75
2.	0207	5	100
3.	0309	8	150
4.	0414	20	250
5.	0617	35	350
6.	0922	60	500
7.	0933	75	750



All dimensions in millimetres.

FIG. 5 STANDARD MOUNTING PLATE

INDIAN STANDARDS ON RESISTORS

IS:

- 824-1965 Preferred values for resistors and capacitors (*revised*)
- 1885 (Part XLVI)-1977 Electrotechnical vocabulary : Part XLVI Resistors
- 5027-1969 Method of measurement of current noise generated in fixed resistors
- 5786 Fixed resistors general purpose, low power:
  - (Part I)-1978 General requirements and methods of tests (*first revision*)
  - (Part II)-1976 Resistors type FR-1
  - (Part III)-1976 Resistors type FR-2
  - (Part IV)-1976 Resistors type FR-3
  - (Part V)-1976 Resistors type FR-4
  - (Part VI)-1976 Resistors type FR-5
  - (Part VII)-1976 Resistors type FR-6
  - (Part VIII)-1976 Resistors type FR-7
  - (Part IX)-1976 Resistors type FR-8
  - (Part X)-1976 Resistors type FR-9
  - (Part XI)-1978 Type FRLP-10
- 8186-1976 Marking codes for values and tolerance of resistors and capacitors
- 8872 (Part I)-1977 Variable resistors : Part I General requirements and methods of tests
- 8909 Fixed resistors, general purpose, power:
  - (Part I)-1978 General requirements and methods of tests
  - (Part II)-1978 Type FRP_1
  - (Part III)-1978 Type FRP_2
  - (Part IV)-1978 Type FRP
  - (Part V)-1978 Type $FRP_4{}^3$
- 9205 (Part I)-1979 Directly heated negative temperature co-efficient thermistors : Part I General requirements and methods of tests
- 8872 (Part II) Variable resistors: Part II General purpose
  - (Part II /Sec 1)-1979 Type VRG 1C
  - (Part II /Sec 2)-1979 Type VRG 2C
  - (Part II /Sec 3)-1979 Type VRG 3C
  - (Part II /Sec 4)-1979 Type VRG 4C
- 8872 (Part III) Variable resistors: Part III Precision
  - (Part III /See 1)-1979 Type VRP 1P
  - (Part III /Sec 2)-1979 Type VRP 2P
- 9470-1979 Method of test for the usability of resistors under pulse conditions
- 9512-1980 Guidance for pulse testing of resistors